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A major tool for afforestation of semi-arid and anthropogenic steppe areas in Turkey: *Pinus nigra* J.F. Arnold subsp. *pallasiana* (Lamb.) Holmboe

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Abstract: In Turkey, almost half of which has semi-arid conditions, steppe areas have continuously been increasing. These areas need to be afforested to prevent desertification. For this purpose, this research presents specifically the Anatolian black pine (*Pinus nigra* J.F. Arnold subsp. *pallasiana* /Lamb./ Holmboe) as a suitable forest tree species for afforestation activities, due to wide distribution both in Turkey and the broader region. After a thorough investigation of past and recent literature, and onsite activities, the review focuses on the production of seeds and seedlings of the species, land preparation and planting technique, post-planting site maintenance, success in the afforestation areas and considerations on Anatolian black pine seed transfer regioning. In conclusion, local ecological conditions regarding the species should always be taken into consideration. Another important issue for the success of afforestation in semi-arid lands is that the preparation activities of the land for afforestation are carried out with appropriate techniques timely and painstakingly. Moreover, after the 2000s, Turkish forestry focused on afforestation in semi-arid and anthropogenic steppe areas. Anatolian black pine is the most widely used tree species in semi-arid lands and anthropogenic areas and plays the major role in successful afforestation.

Keywords: Anatolian black pine; extreme conditions; seedling; seed transfer region

The Middle East and Mediterranean basin, which includes Turkey, whose 2/3 of its area are located in the arid and semi-arid climate zone, are under severe drought and desertification threat. While the unfavourable climatic and soil conditions result in the natural vegetation as steppe especially in the Central Anatolia Region, the main problems apart from the natural steppe are anthropogenic. While the natural steppe areas in the middle of Anatolia covered a narrower region until about 4 000 years ago, these areas have gradually expanded with the ongoing degradation throughout history (Doğan 2011; Yıldız et al. 2018a; Barbati et al. 2018). The steppe proportion in the Anatolian peninsula accounted for around 17% in the years 10 000 BC but it has increased to 35% today (Çepel 1995). Inconsistent land management with deforestation and erosion in semi-arid areas resulted in soil degradation and the loss of plant species (WMO 2007; Mutlu 2019). Semi-arid and steppe regions have been created by climatic and anthropogenic factors in the historical processes (Yıldız 2019). Steady

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grazing and agricultural activities in the semi-arid regions of Inner Anatolia have also decreased the portion of vegetation cover (Yıldız et al. 2017). In total 37.3% of Turkey's land cover is under semi-arid climate conditions (Turan 2018).

Afforestation plays an important role in preventing soil degradation and conserving biodiversity in the semi-arid areas under the negative influence of climate change (Leslie et al. 1992). Under conditions of drought-heat stress, regarding the costs of the planting, the most important variable was the number of seedlings, followed by the planting stock type. Weeding requirements and other post-planting care come secondary. Therefore, if the number of individuals can be reduced by using the stocks of large-sized transplants, the costs of establishing a plantation can be significantly reduced in the Czech Republic (Gallo et al. 2020a). So far, positive effects were determined on (*i*) soil quality of sand dunes in 35-year-old acacia (*Acacia cyanopylla* Lindley), *Eucalyptus* L'Hér., and stone pine (*Pinus pinea* L.) afforestation (Akça et al. 2010); (*ii*) on electrical conductivity and soil microbial respiration in 23-year-old black pine (*Pinus nigra* J. F. Arnold) afforestation (Kaptanoğlu Berber et al. 2014); (*iii*) on soil porosity, capillary and gravitational pores in 41-year-old afforestation with eight forest tree species (Podrázský et al. 2015); (*iv*) on organic matter, phosphorus, nitrogen, clay, dust, field capacity, wilting point and available water capacity in 13-year-old black pine afforestation (Yazici, Turan 2016); (*v*) on hydrophysically important soil properties and soil loss per unit area in 40-year-old black pine afforestation (Hacisalihoglu 2018), and (*vi*) investigated to compare production parameters, structure and diversity of seven pine stands (as exotic species: *Pinus ponderosa* Douglas ex C. Hawson, *Pinus jeffreyi* Balf., *Pinus nigra* J.F. Arnold, *Pinus strobus* L., *Pinus contorta* Douglas, *Pinus peuce* Griseb. and as native species: *Pinus sylvestris* L.) at the age of 35 years in Central Bohemia (320 m a.s.l., medium rich habitats, water deficit site) (Podrázský et al. 2020). As a matter of fact, *P. nigra* has already been suggested as an alternative species for unfavourable soil conditions particularly against the changing climate conditions in Central Europe (Thurm et al. 2018). On this issue Gallo et al. (2020b) recommended that the achievement of sustainable forest management requires the incorporation of ongoing environmental changes into long-term planning. Large-scale semi-arid afforestation can increase precipitation and carbon sequestration potential (Yosef et al. 2018). Black pine afforestation has an efficient role in altering local climate by air temperature and humidity (Mikulová et al. 2019). Zhiyanski et al. (2016) revealed that Douglas fir, black pine and Scots pine afforestation of cropland turned the soil into a C sink in the Western Rhodope Mountains (Bulgaria). Furthermore, afforestation with such species (Scots pine, Black pine) can be used for erosion protection on specific extreme sites such as reclaimed sites (Vacek et al. 2021).

In Turkey, a total of 2 464 487 ha of land was afforested between 1946 and 2018 (OGM 2018). Successful large-scale afforestation activities with mainly coniferous species have been carried out during the last decades to mitigate soil erosion. In the afforestation measures of Turkey, fast-growing species instead of natural species have mostly been used to mitigate soil erosion, restore vegetation, biomass production (Ayan, Sıvacıoglu 2006; Eshaibi et al. 2020), and improve site conditions. However, diversity index was found significantly greater in native *Quercus* spp. forests than in exotic coniferous afforestation (Mutlu 2019). The black pine is one of the most widely used tree species for afforestation and reforestation in the Republic of North Macedonia, but considering the elevation and the local environmental factors, the species develop much better features at higher altitudes (altitude of 500 m a.s.l. and above) rather than struggling on both lower and xeric sites, whereas they should not be planted going under species ecological boundaries (Trendafilov et al. 2010). On the other hand, referring to the Anatolian black pine subspecies which occur rarely in this country, as phenotypically modest, yet with high genetic heterogeneity (Andonoski 1980), Vilarov (1971) concluded that it is slowly, but assuredly regenerating and colonizing new arid and erosive sub-Mediterranean areas at the locality of Cham Chiflik, in open space in pseudo-maquis (about 250–500 m a.s.l.), on the western borderline of the subspecies distribution. Actually, black pine is one of the most important coniferous species for afforestation of dry and rocky lands in the sub-Mediterranean zone (Barčić et al. 2020) and for mountainous and hilly lands in the Prealps and Apennines (Freer-Smith et al. 2019). *P. nigra* has a lower slenderness ratio than *Picea abies* (L.) H. Karst. in the area above treeline ecotones of Hyrcanian forests, with an altitude from 1 550

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to 1 650 m in Ardebil province, north of Iran, and hence it is more tolerant to the extreme climate conditions (Tavankar et al. 2018). Resistance of this species to extreme climate conditions makes it the first tree species to be used for afforestation of semi-arid areas in Turkey (Karadağ 1999; Öner, İmal 2007; Semerci et al. 2008; Gökdemir et al. 2012; Çolak et al. 2014; Ayan et al. 2017; Pach et al. 2018). The afforestation with *P. nigra* significantly increased density (number of stems per hectare) and species richness of woody plants (Tavankar et al. 2018). Previous research noted that *P. nigra* improved landscape aesthetics more (Panagopoulos, Hatzistathis 1995; Gökdemir et al. 2012; Gültekin 2014) and was more efficient in C storage (Lukić et al. 2015) compared to *R. pseudoacacia*. In this regard, afforestation by planting and seeding Anatolian black pine (*P. n.* J.F. Arnold subsp. *pallasiana* /Lamb./ Holmboe, syn: *P. n.* J.F. Arnold subsp. *caramanica* /Loudon/ Businský) is a fundamental tool for the establishment of new resilient forests in semi-arid areas in Turkey.

According to Farjon (2010), *P. nigra* Arnold is divided into five subspecies. The subspecies are: (1) subsp. *nigra*; (2) subsp. *dalmatica* (Vis.) Franko; (3) subsp. *laricio* Maire; (4) subsp. *pallasiana* (Lamb.) Holmboe; (5) subsp. *salzmannii* (Dunal) Franko. *P. nigra* has a large natural range in northern Africa, Crimea, Europe, and Anatolia, and is one of the controversial species of systematics. In studies on this species, classifications were made in different categories on the basis of sub-taxa (Kayacık 1980; Christensen 1993; Sıvacıoğlu, Ayan 2008; Akkemik et al. 2010; Oral, Mataracı 2018). In Turkey, some varieties of this subspecies were identified: var. *seneriana* (Saatçioğlu 1955), var. *pyramidata* (Acatay 1956), var. *yaltirikiana* (Alptekin 1986) and var. *columnaris-pendula* (Boydak 2001). A study titled "*Geographical variations of Anatolian black pine*", conducted by systematically sampling 89 natural populations of Turkey and 3 populations outside the borders of Turkey, identified 15 geographical variations for Turkey (Alptekin 1987). Furthermore, investigations were carried out to determine the impact of ecological characteristics and ecoregion on the natural distribution of Anatolian black pine in Turkey. The results are as follows: 6 ecoregions exist and climate, parent material, topography, anthropogenic factors, floristic composition, competition are ecological factors that determine the distribution. But climatic elements such as precipitation and temperature are the dominant factors. The six ecoregions with different characteristics have been identified and distribution of the species revealed, depending on ecological features of each region. Productive Anatolian black pine forests are found on the subhumid-semiarid areas. The poor and/or lowest productive stands occur in the semi-arid parts of Inner Anatolia. The species can grow on all material in the semi-arid and subhumid cold climates, but deep weathered parent materials are the best for the growth of Anatolian black pine.

The taxon, i.e., as one of the subspecies of the European black pine, in Turkey occurs naturally and widely in Taurus, western Anatolian and northern Anatolian Mountains. It ranges from 250 to 1 550 m in altitude (Kaya, Temerit 1994). Fire is an important factor in the explanation of the distribution of this species (Barčić et al. 2020). It is one of the most common and important forest tree species in Turkey because of the commercial use of its wood (Sıvacıoğlu, Ayan 2010). The area of occupancy is about 4.2 million ha in Turkey (Anonymous 2015).

This review paper focuses on Anatolian black pine, which is one of the dominant subspecies in Turkey both ecologically and economically. Specifically, it presents the production of planting stock of Anatolian black pine and its role in afforestation in Turkey.

PRODUCTION OF BLACK PINE PLANTING STOCK

Seed production. In general, Anatolian black pine starts cone production at the age of 15–20 years in its natural range. It produces heavy seed crops every 2–3 years depending on the physiographic factors (elevation, aspect etc.). The cones ripen in September or November of the second year production and can be collected from November. The seeds of the cones collected in February or March have the highest germination ability (Atahan 1986; Gezer, Yücedağ 2013). The mean 1 000 seed weight of the subspecies seeds is 22.5 g. One kg of these cones contains an average of 44 450 seeds (ÇEMGM 2013). Seeds are easily extracted from the cones by using sun drying or keeping in a well-aerated warm room (Gülcü 2002).

Seed sources of the subspecies are available in Turkey and are registered in the National Register System. Accordingly, the total seed source area (16 128.9 ha) consists of seed stands (71 pcs

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– 9 065.1 ha), seed orchards (55 pcs – 473.1 ha) and gene conservation forest (42 pcs – 6 590.7 ha) (OGM 2021a). In a study conducted by Bilir (2021) on active clonal seed orchards of Anatolian black pine, the values obtained by the number of clones, the number of effective clones and genetic diversity are given in Table 1. Seeds obtained from these sources are used in the production of quality seedlings and thus the success of afforestation has been increased. Moreover, in a study conducted by Çilgin et al. (2007) in the 9-years-old clonal seed orchard of Hanönü (Kastamonu) – Günlüburun Anatolian black pine, it was found that variation is based on clone in 11 out of the 12 traits measured in terms of cone, seed, and seedling.

Seedling production. Seeds of the subspecies are sown without any pre-treatment (Gezer, Yücedağ 2013). They are only soaked in aerated tap water for 24 h before sowing (Temel et al. 2011). Ayan et al. (2020) stated that the heat shock treatments of 70 °C for 5 min, 90 °C for 1 and 5 min, 110 °C for 1 min and 130 °C for 1 min increased germination percentage. In addition, Ayan and Usta (2010) found that the percentage of seed germination and seed vitality significantly decreased when the seeds were exposed to heat over 5 min under the heat higher than 120 °C in Scots pine, Anatolian black pine and Turkish pine. In another research (Çelikbaş 2019), it was noted that Ag, Fe_3O_4, Fe_2O_3, ZnO and silica nanoparticles with high concentration, and CuO_2 and TiO_2 with low concentration had positive effects on seed germination of the subspecies. The same investigation presented that the thickness of the radicle in a control group was higher than in the applications of nanoparticles.

Seeds are sown at a depth of 1 to 1.5 cm between March and May, depending on the climate and altitude of the nursery. The seedling density at seedbeds should be kept at 250–300 seedlings per m^2 for the subspecies (Gezer, Yücedağ 2013). However, Güner et al. (2008a) and Akbulut (2019) reported that wider sowing spacing resulted in better seedling growth of the subspecies. A research (Devetaković et al. 2020) completed in the nursery of the Faculty of Forestry – University of Belgrade, Serbia showed that the best seedlings of *P. nigra* were obtained from a combination of lower sowing density (20 $g \cdot m^{-2}$) with sowing across the entire seedbed space.

A study (Kolevska et al. 2020), conducted in the forest nursery in Sveti Nikole, Rebuplic of North Macedonia, suggested that *P. nigra* seedlings grown in Yukosad containers (hard plastic, 75 cm^3, 610 seedlings$\cdot m^{-2}$) had higher morphological traits, but the seedlings grown in Siset containers (grey cardboard with white coating, 128 cm^3, 589 seedlings$\cdot m^{-2}$) had better values of quality indices and ratios. In contrast, Kostopoulou et al. (2011) stated that *P. nigra* seedlings had developed longer roots in deep containers.

The periods from mid-May to mid-June, early July to mid-August and mid-September to late October were determined as seeding, growing and fast-growing, slowing and lignification phases for 1-year-old seedlings, respectively. Dormancy-end, growing and fast-growing, slowing and lignification phases in 2-year-old seedlings of the subspecies were defined as the periods from early March to mid-April, early May to late July, mid-August to early November, respectively (Yer, Ayan 2011). Another study, exploring the effect of desiccation during cold storage on planting stock quality and field performance in *P. n.* subsp. *laricio* var. *corsicana* Loudon, showed that root growth potential and survival after outplanting decreased with desiccation duration (Garriou et al. 2000).

The highest percentages of the roots of the subspecies are found as 37.04% in twice lateral pruning with undercutting (Çetinkaya, Deligöz 2012) and 18.25% in once root pruning (Avanoğlu et al. 2005). According to TS 2265/ March 1976, the quality seedlings were obtained from applying once lat-

Table 1. Number of average clones and number and percentage of effective clones, coefficient of variation and gene diversity values in Anatolian black pine clonal seed orchards in Turkey (Bilir 2021)

Species	N	N_c	N_r	C_v	GD
P. n. subsp. *pallasiana*	32.3	28.2	0.90	31.5	0.981
	10–120*	9.3–77.5*	0.65–0.99*	4.6–74*	0.976–0.994*

*minimum and maximum values; N – number of average clones; N_c – number of effective clones; N_r – percentage of effective clones ($N_r = N/N_c$); C_v – coefficient of variation; GD – gene diversity

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eral pruning with undercutting in June (Çetinkaya, Deligöz 2012). The production of seedlings with root systems that meet better morphological and physiological standards is essential to enable them to rapidly establish and thrive upon field performance (Davis, Jacobs 2005).

It is suggested that higher root-collar diameter and number of lateral roots in seedlings of the subspecies can be obtained with the application of potassium nutrition in the nursery phase for the success in afforestation of semi-arid areas (Çömez, Gezgin 2019). Deligöz (2012) revealed that autumn fertilizing with 10 g nitrogen per square metre is useful for seedling height. Moreover, mycorrhiza inoculation at the nursery stage was found to be effective only on root length. Especially, *Rhizopogon* Fr. (1817) inoculation was suggested to obtain healthy and well-growing seedlings of the subspecies (OGM 2013). Lazarević et al. (2012) reported that the use of vegetative and spore inoculums of autochthonous *Suillus granulatus* (L.) Roussel (1796) proved to be an effective method of obtaining containerized ectomycorrhizal *P. nigra* seedlings under open field conditions after 11 months.

According to the root/shoot ratio of the subspecies, two-years-old seedlings were generally considered to be of better-quality, while three-years-old seedlings were unstable. It was suggested that three-years-old seedlings should not be used in its plantations (Akgül 2010). Total seedling production of the subspecies per year across Turkey from 2009 to 2019 is available in Figure 1. Accordingly, seedling production virtually decreased by half.

AFFORESTATION WITH ANATOLIAN BLACK PINE IN TURKEY

Land preparation and planting technique. In Turkey, deep and shallow soil tillage is done on the whole area prior to planting and at the beginning of the dry season after planting, respectively (Boydak, Çalışkan 2015). It should not be forgotten that especially deep soil tillage more than planned may cause salinization of the soil by evaporating the calcareous, salty and alkaline substances accumulated in the subsoil (Öner et al. 2016). So, on semi-arid land, the soil should be cultivated at a depth of 30 cm before planting (Gezer, Yücedağ 2006). If topography is suitable in semi-arid areas of Turkey, soil tillage is performed by machinery to increase the water absorption and improve the root development of the seedlings. Where the machine tillage is not possible, gradoni terraces are manually established. In the 0–40% inclined lands, subsoil cultivation at a depth of 60–80 cm is generally carried out by a tracked tractor + ripper for land preparation. After the subsoil cultivation, top soil cultivation in gradoni terraces with a depth of 35–45 cm and a width of 80–100 cm can be performed usually by a 4 × 4 rubber-tired

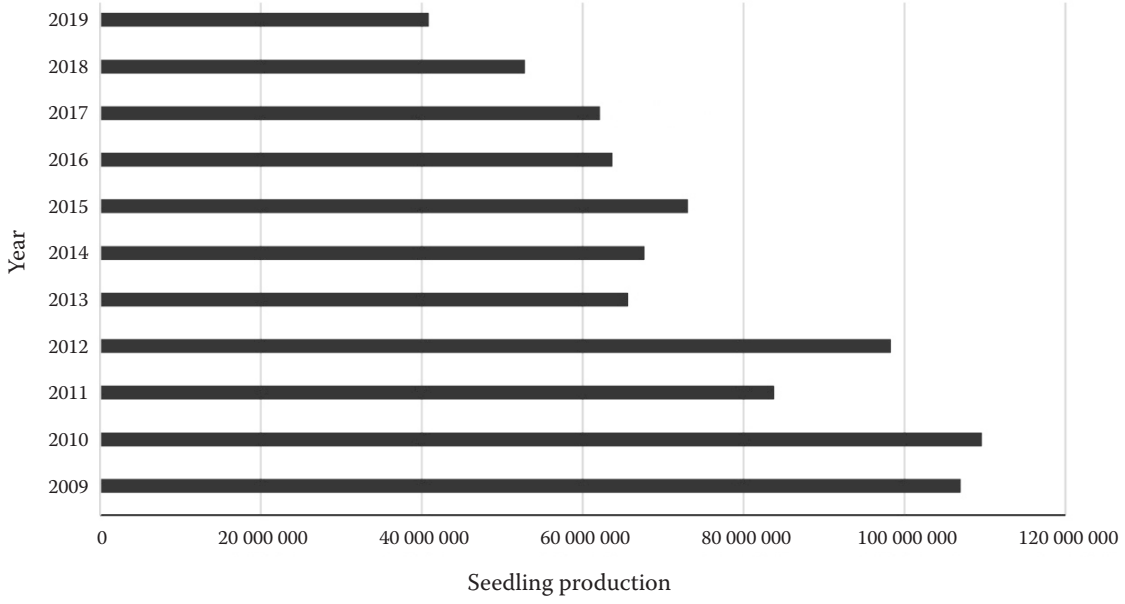

Figure 1. Anatolian black pine seedling production by year in Turkey (OGM 2021a)

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tractor + double ripper in parallel with the contour lines. Working with an excavator has been preferred in small areas that are unsuitable for a tracked tractor. In erosion control works where the slope exceeds 40%, a tracked or rubber-tired mini excavator with a minimum of 24 HP and a maximum axle width of 200 cm has been used (Yıldız et al. 2018b). Researches completed by Gülcü and Çelik (2016a, b) in Karaman-Turkey reported that double or triple ripper + gradoni terrace should be used for the soil tillage in *P. n.* subsp. *caramanica* afforestation on semi-arid areas due to their both positive contribution to seedling traits, and economic and application easiness. A study (Öz, Göl 2021) conducted in Çankırı showed that the BUROR terrace field preparation had the highest seedling survival and growth. Furthermore, Dassot and Collet (2021) stated that the root development of 5-years-old *P. n.* subsp*. laricio* Maire seedlings in northwestern France in the Normandy region was better on the sites prepared by machinery. A research (Erkan 1998) completed in Elazığ also stressed that the growth of *P. nigra* was very good particularly in the areas with deep soils.

Planting time, planting distance, soil amendments, nursery practices, and seedling type are of great importance in semi-arid areas (Ayan et al. 2006; Ayan 2007; Ertekin et al. 2010). Planting in such areas should be carried out in early spring (Öner et al. 2016). It is imperative to use wide spacing in planting (Gezer, Yücedağ 2006; Sıvacıoğlu et al. 2006; Çalışkan, Boydak 2017). In particular for coniferous species such as *P. nigra*, containerized seedlings should be used (Gezer, Yücedağ 2006; ÇEMGM 2013; Öner et al. 2016).

If bare-rooted seedlings are used in afforestation of semi-arid lands, especially for coniferous species, the stem to root ratio should be ideally between 2 and 2.5 (ÇEMGM 2013). Although Deligöz et al. (2009) stated that *P. nigra* seedlings in quality class 4 (minimum collar diameter is 4 mm and minimum seedling height is 10 cm) were the most suitable to outplanting as they had the best survival and growth. Furthermore, Karabulut (2004) stated that shallow soil tillage can be done after clearing the vegetation cover with rake, and 1-year-old bare-rooted *P. nigra* seedlings can be used successfully in planting to deal with the planting stress easily and obtain a higher survival ratio. Planting shock has lasted for two years in Anatolian black pine (Deligöz et al. 2009). Another research (Bulíř 2006) reported that *P. nigra* seedlings treated with Silvamix Forte in a seven-year experiment on Loket spoil bank exceeded the control plants by 46.2 cm. Dirik (1994) emphasized that seedling freshness was very effective on the survival of black pine afforestation.

Along with *P. n.* subsp. *pallasiana*, the most commonly used coniferous and broadleaf species in Inner Anatolia (Figure 2) are as follows: *Cedrus libani* A. Rich., *Cupressus arizonica* Greene, *Juniperus excelsa* Bieb. *J. oxycedrus, J. foetidissima*) and *Thuja* L. spp., *Robinia pseudoacacia* L., *Ailanthus altissima* (Mill.) Swingle, *Quercus pubescens* Willd., *Q. infectoria* Olivier, *Q. robur* L., *Q. cerris* L., *Elaeagnus angustifolia* L., *Gleditsia triacanthos* L., *Calligonum polygonoides* L., *T. germanica* L., *Pyrus elaeagnifolia* Pall., *Crataegus monogyna* Jacq., and *Prunus mahaleb* L., (Öner et al. 2016; Yıldız et al. 2018a).

Post-planting site maintenance. With the maintenance activities, it is aimed to increase the resistance of seedlings against the negative effects that may occur during the period from planting to their biological independence (3–7 years), provide their protection, and improve their growth. Although maintenance works are generally carried out manually, they can be done with machinery in suitable terrains (ÇEMGM 2013).

On semi-arid land, it should be cared about hoeing and weeding among intensive maintenance measures (Öner, Eken 2014). Other maintenance measures such as soil protection to increase success (annual crop rotation, contour and mixed crop cultivations, reduced and zero tillage, establishment of windbreaks and terracing, drip irrigation method) should also be included in applications as far as possible (Öner et al. 2016). Along with afforestation, mechanical measures such as terracing watersheds of dams and installing barriers and fences in plantations should be applied (Reis et al. 2007).

The hoeing-weeding is done at the beginning of the vegetation period following the planting or after the spring rains, before the seeds of the weeds ripen and shed. Manual hoeing-weeding is performed around the seedling from the outside to the inside in the first year and from the inside to the outside in the second and third year. It should be done either on the planting lines or on strips extending 60–80 cm or 50–60 cm on both sides of the planted seedlings, respectively, depending on the weed species, weed height, and weed density. Hoeing is done deep in fine-textured soils and shallow in coarse-textured soils (ÇEMGM 2013).

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A vegetation period after the planting on the site, completion is done in the areas seen in collective drying or the drying exceeding 20% in dispersed form. In the periods following the planting, terrace repair should be done during the hoeing-weeding process, as there may be deterioration and tearing in the terraces due to rainfall (ÇEMGM 2013).

Success in Anatolian black pine afforestation. Correlations between morphological attributes and field performance in *P. n.* subsp. *nigra* var. *nigra* were stronger for the plot with shallower soil, having potentially drier conditions. Morphological features better forecasted field performance in the first three years at the shallow soil site, with the number of the first order lateral roots being

Figure 2. Photographs of afforestation examples in Inner Anatolia (Photo: O. Yildiz)

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the best single morphological variable. Height and root dry weight were the best attributes to forecast growth during the first three years after planting on both sites (Ivetić et al. 2016).

Survival rate of *P. nigra* was found to be 15% in 9-year-old in the Inner Anatolia Region (Şimşek et al. 1995), 30% in 8-year-old in the Inner Anatolia Region (Yıldız et al. 2018a), 36% in 25-year-old in Eskişehir (Gökdemir et al. 2012), 43% in 2-year-old in Karaman (Gülcü, Çelik 2016a), 39% in 4-year-old in Karaman (Gülcü, Çelik 2016b), 41% in Isparta and 60% in Mersin in 21-year-old (Coşgun et al. 2007), 60% in 39-year-old in Konya (Kantarcı et al. 2011), 63% in 7-year-old in the Inner Anatolia Region (Toprak 2016), 68% in 21-year-old in the Marmara region (Tosun et al. 2011), 79% in 12-year-old in Çankırı (Öner et al. 2015), 70% in 11-year-old in Denizli (Gülbaş 2016) and in Isparta (Çetin 2017), 85% in 21-year-old in the western Black Sea Region (Tosun et al. 2011), 86% in 5-year-old in Çankırı (Kondur et al. 2007; Yılmaz et al. 2007; Öner, Sıvacıoğlu 2010), 90% in 5-year-old in Kütahya (Güner et al. 2008b), 95% in 5-year-old and 96% in 15-year-old in the Aegean Region (Doğan, Acar 2004; Acar et al. 2010) and 99% in 4-year-old black pine in Eskişehir (Yücel 2002).

The seedling types (containerized, bare-rooted) used in these studies, precipitation and altitude of their trial sites (Yıldız et al. 2018a), former status of afforestation area (e.g. burned area; Yücel 2002), their growing conditions in a nursery, and planting techniques in trial sites may cause a variability in the survival rates of *P. nigra*. Ertekin and Özel (2010) also reported that there were differences both in the region and aspect in terms of survival ratio and seedling growth in Anatolian black pine plantations in Çorum, Turkey. A study (Göl, Yel 2016) exploring the success of different forest tree species in the afforestation area of Çankırı Forestry Faculty reported that black pine had the highest survival rate compared to the other species. Accordingly, afforestation on the west-facing aspect was found as successful compared to the other aspects.

Black pine afforestation in Devrek-Akçasu (Tufanoğlu 2009) and Bartın (Tunçtaner et al. 2007) districts of Turkey is at a satisfactory level in terms of growth characteristics, but their survival ratios are unsuccessful. Mean diameter at breast height and height of 20-years-old *P. nigra* afforestation in above-treeline mountain areas in the north of Iran was found as 22.6 cm and 8.04 m, respectively (Tavankar et al. 2018). Six-years-old *P. nigra* seedlings had the highest diameter (8.76 cm) and the lowest height (2.33 m) compared to *Pinus brutia* and *Cedrus libani* in an afforested site in Ankara (Tonguç, Arslantaş 2019).

A research assessing the rehabilitation works in Burdur showed that Anatolian black pine should be preferred over *Cedrus libani* in semi-arid land afforestation which especially has heavy-textured soils with an aeration problem. The increase in lime content and pH of the soil negatively affects the growth of the subspecies (Çetin 2014). On the other hand, a study (Adamenko et al. 2018) exploring the seasonal growth of *P. nigra* under the climatic conditions of the Right-Bank-Forest-Steppe of Ukraine revealed that the mechanisms regulating its growth processes were positively correlated with the air temperature, the onset of shoot growth required a small amount of heat, and the needle growth started in 30–35 days after the beginning of shoot growth. Deligöz et al. (2018), studying seasonal and needle age-related variations in the biochemical characteristics of *P. n.* subsp. *pallasiana* owing to the closely linked associations between plant growth and photosynthesis, reported that needle age and seasons affected carbohydrate and pigment contents.

Black pine had better growth on slopes than on flat areas. In terms of the slope position, its height increased from the upper slope to the lower slope. For this reason, it should be primarily planted on lower and middle slopes of afforestation areas (Güner et al. 2016).

SEED TRANSFER REGIONS OF ANATOLIAN BLACK PINE IN TURKEY

Sustainable and successful afforestation activities are realized by establishing seed transfer regioning relying on the ecological conditions. The seed transfer regioning mainly aims to sustain seed transfer within the same subregion (Atalay, Efe 2010). This aim is provided from the provenance tests determining the regions with suitable parental material for afforestation activities (Gezer et al. 2006). Overlooked local ecological conditions will most probably bring about unsuccessful afforestation. Therefore, Atalay and Efe (2010) split the Anatolian black pine forests into six main seed transfer regions depending on the climatic types.

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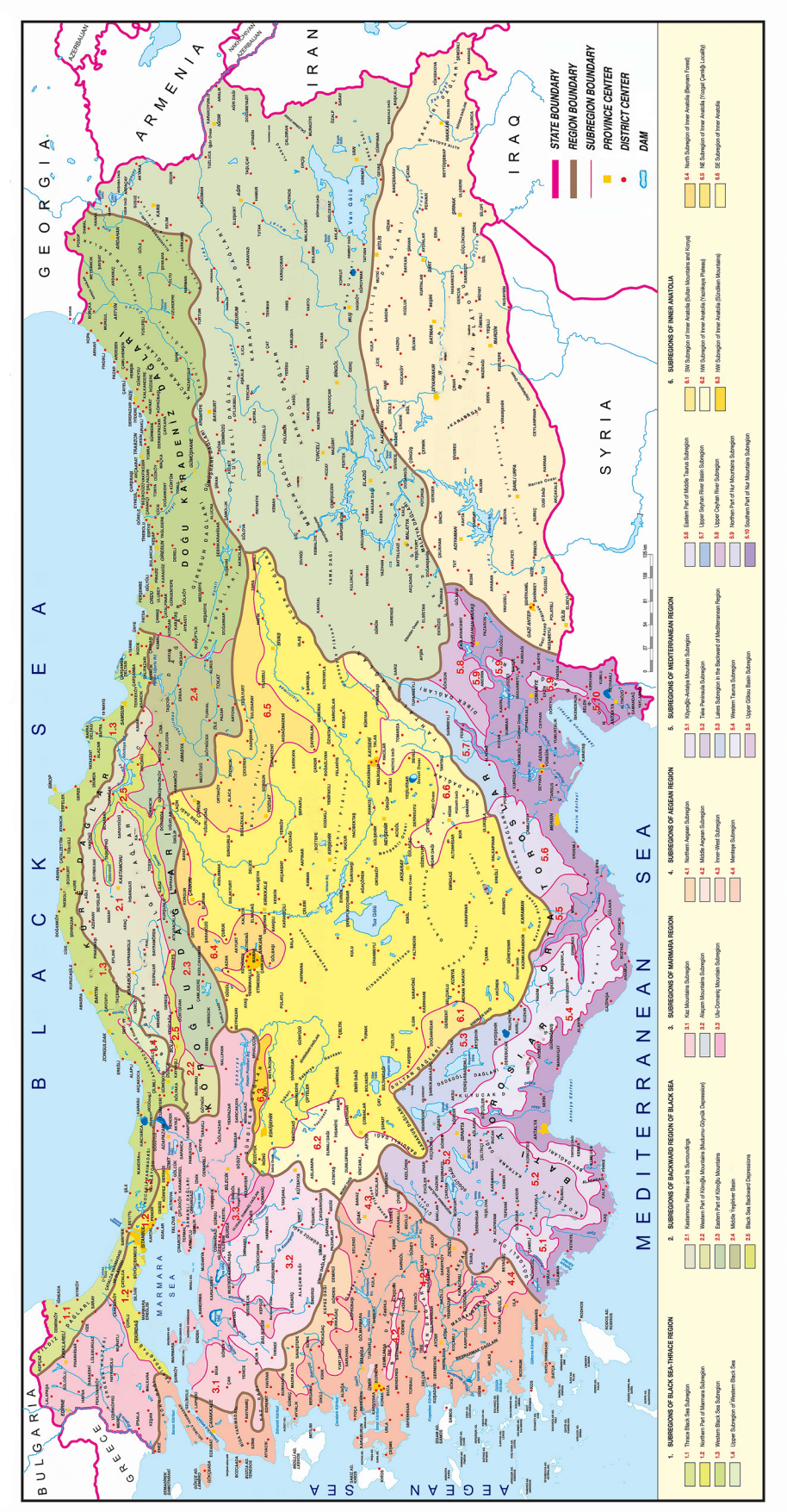

Figure 3. Seed transfer regions and subregions of Anatolian black pine (modified from OGM 2021b)

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These regions are as follows: the Coastal Region of Black Sea Thrace (four subregions), Backward Region of Black Sea (five subregions), Marmara Region (three subregions), Aegean Region (four subregions), Mediterranean Region (ten subregions) and Inner Anatolian Region (six subregions) (Figure 3).

The seeds collected from the seed stands in one subregion must be used for the same subregion. If the subregion has no seed stand, then the seed material must be collected from the seed stands of adjacent subregion depending on the elevation and exposure. The longest seed transfer distance in the vertical direction must be between +150 and –200 m. The afforestation areas of black pine must be selected from its optimum growing areas mostly found at an elevation of 1 000–1 700 m without the coastal region of the Black Sea. Seed transfer must be done between the same exposures and the same parent materials. Planting should be performed on the deeply ploughed areas. Anatolian black pine afforestation activities should not be done within the humid-mild forest region to avoid its displacement with deciduous trees (Atalay, Efe 2010).

CONCLUSION

It is enormously crucial to commence and sustain afforestation activities in semi-arid and anthropogenic steppe areas of Turkey, and hence socioeconomically and ecologically to meet the forest needs of the region. Appropriate selection of forest tree species is the first important step for the success of afforestation activity. In this sense, this research suggests (Anatolian) black pine for deforested areas of Turkey, a tree with wide distribution both in Turkey and the broader region. Although there are available successful afforestation examples, local environmental factors, i.e., site conditions regarding the species should always be taken into consideration. In addition, the number of provenance tests established for the species should be increased to select the most suitable provenances. The number of seed sources of the species should also be increased, and they should be well protected. Another important issue for the success of afforestation in semi-arid lands is that the preparation activities of afforestation are carried out with appropriate techniques timely and painstakingly.

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